Programming Languages and Compilers (CS 421)

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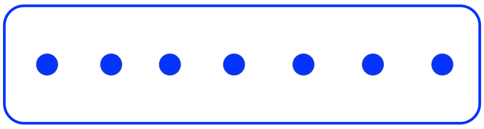
Based in part on slides by Mattox Beckman, as updated by Vikram Adve and Gul Agha

Variants - Syntax (slightly simplified)

- type *name* = C_1 [of ty_1] | . . . | C_n [of ty_n]
- Introduce a type called *name*
- (fun x -> C_i x) : ty_1 -> *name*
- C_i is called a *constructor*; if the optional type argument is omitted, it is called a *constant*
- Constructors are the basis of almost all pattern matching

Enumeration Types as Variants

An enumeration type is a collection of distinct values



In C and Ocaml they have an order structure; order by order of input

Enumeration Types as Variants

```
# type weekday = Monday | Tuesday | Wednesday
  | Thursday | Friday | Saturday | Sunday;;
type weekday =
    Monday
  | Tuesday
  | Wednesday
  | Thursday
  | Friday
  | Saturday
  | Sunday
```


Functions over Enumerations

```
# let day_after day = match day with
     Monday -> Tuesday
   | Tuesday -> Wednesday
   | Wednesday -> Thursday
   | Thursday -> Friday
   | Friday -> Saturday
   | Saturday -> Sunday
   | Sunday -> Monday;;
val day_after : weekday -> weekday = <fun>
```


Functions over Enumerations

```
# let rec days_later n day =
    match n with 0 -> day
    | _ -> if n > 0
         then day_after (days_later (n - 1) day)
         else days_later (n + 7) day;;
val days_later : int -> weekday -> weekday
  = <fun>
```

Functions over Enumerations

```
# days_later 2 Tuesday;;
- : weekday = Thursday
# days_later (-1) Wednesday;;
- : weekday = Tuesday
# days_later (-4) Monday;;
- : weekday = Thursday
```


Problem:

```
# type weekday = Monday | Tuesday | Wednesday
  | Thursday | Friday | Saturday | Sunday;;
```

- Write function is_weekend : weekday -> bool

```
let is_weekend day =
```


Problem:

```
# type weekday = Monday | Tuesday | Wednesday
  | Thursday | Friday | Saturday | Sunday;;
```

- Write function is_weekend : weekday -> bool

```
let is_weekend day =
    match day with Saturday -> true
     | Sunday -> true
     | _ -> false
```

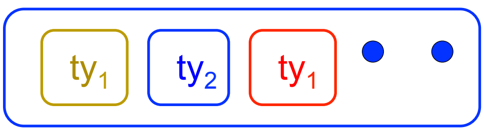

Example Enumeration Types

```
# type bin_op = IntPlusOp |  IntMinusOp
        |  EqOp | CommaOp | ConsOp

# type mon_op = HdOp | TlOp | FstOp
        | SndOp
```


Disjoint Union Types

- Disjoint union of types, with some possibly occurring more than once



- We can also add in some new singleton elements

Disjoint Union Types

```
# type id = DriversLicense of int
  | SocialSecurity of int | Name of string;;
type id = DriversLicense of int | SocialSecurity
  of int | Name of string
# let check_id id = match id with
    DriversLicense num ->
     not (List.mem num [13570; 99999])
   | SocialSecurity num -> num < 900000000
   | Name str -> not (str = "John Doe");;
 val check_id : id -> bool = <fun>
```

Problem

- Create a type to represent the currencies for US, UK, Europe and Japan

Problem

- Create a type to represent the currencies for US, UK, Europe and Japan

```
type currency =
   Dollar of int
 | Pound of int
 | Euro of int
 | Yen of int
```


Example Disjoint Union Type

```
# type const =
     BoolConst of bool
   | IntConst of int
   | FloatConst of float
   | StringConst of string
   | NilConst
   | UnitConst
```


Example Disjoint Union Type

```
# type const = BoolConst of bool
    | IntConst of int | FloatConst of float
    | StringConst of string  | NilConst
    | UnitConst
```

- How to represent 7 as a const?
- Answer: IntConst 7

Polymorphism in Variants

- The type 'a option is gives us something to represent non-existence or failure

```
# type 'a option = Some of 'a | None;;
type 'a option = Some of 'a | None
```

- Used to encode partial functions
- Often can replace the raising of an exception

Functions producing option

```
# let rec first p list =
   match list with [ ] -> None
   | (x::xs) -> if p x then Some x else first p xs;;
val first : ('a -> bool) -> 'a list -> 'a option = <fun>
# first (fun x -> x > 3) [1;3;4;2;5];;
- : int option = Some 4
# first (fun x -> x > 5) [1;3;4;2;5];;
- : int option = None
```

Functions over option

```
# let result_ok r =
   match r with None -> false
   | Some _ -> true;;
val result_ok : 'a option -> bool = <fun>
# result_ok (first (fun x -> x > 3) [1;3;4;2;5]);;
- : bool = true
# result_ok (first (fun x -> x > 5) [1;3;4;2;5]);;
- : bool = false
```


Problem

- Write a hd and tl on lists that doesn't raise an exception and works at all types of lists.

Problem

- Write a hd and tl on lists that doesn't raise an exception and works at all types of lists.

- ```
  let hd list =
      match list with [] -> None
       | (x::xs) -> Some x
  ```
- ```
  let tl list =
      match list with [] -> None
       | (x::xs) -> Some xs
  ```


Mapping over Variants

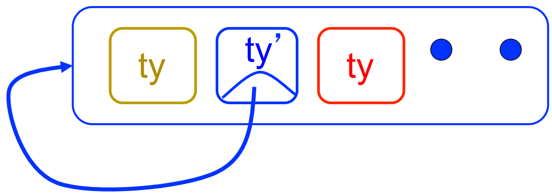
```
# let optionMap f opt =
    match opt with None -> None
    | Some x -> Some (f x);;
val optionMap : ('a -> 'b) -> 'a option -> 'b
  option = <fun>
# optionMap
  (fun x -> x - 2)
  (first (fun x -> x > 3) [1;3;4;2;5]);;
- : int option = Some 2
```


Folding over Variants

```
# let optionFold someFun noneVal opt =
    match opt with None -> noneVal
    | Some x -> someFun x;;
val optionFold : ('a -> 'b) -> 'b -> 'a option ->
  'b = <fun>
# let optionMap f opt =
    optionFold (fun x -> Some (f x)) None opt;;
val optionMap : ('a -> 'b) -> 'a option -> 'b
  option = <fun>
```


Recursive Types

- The type being defined may be a component of itself



Recursive Data Types

```
# type exp =
   VarExp of string
  | ConstExp of const
  | MonOpAppExp of mon_op * exp
  | BinOpAppExp of bin_op * exp * exp
  | IfExpofexp* exp * exp
  | AppExp of exp * exp
  | FunExp of string * exp
```


Recursive Data Types

```
# type bin_op = IntPlusOp |  IntMinusOp
        | EqOp | CommaOp | ConsOp | …
# type const = BoolConst of bool | IntConst of int |
…
# type exp = VarExp of string | ConstExp of const
   | BinOpAppExp of bin_op * exp * exp  | …
```

- How to represent 6 as an exp?

Recursive Data Types

```
# type bin_op = IntPlusOp |  IntMinusOp
        | EqOp | CommaOp | ConsOp | …
# type const = BoolConst of bool | IntConst of int |
…
# type exp = VarExp of string | ConstExp of const
   | BinOpAppExp of bin_op * exp * exp  | …
```

- How to represent 6 as an exp?
- Answer: ConstExp (IntConst 6)

Recursive Data Types

```
# type bin_op = IntPlusOp |  IntMinusOp
        | EqOp | CommaOp | ConsOp | …
# type const = BoolConst of bool | IntConst of int |
…
# type exp = VarExp of string | ConstExp of const
   | BinOpAppExp of bin_op * exp * exp  | …
```

- How to represent (6, 3) as an exp?

Recursive Data Types

```
# type bin_op = IntPlusOp |  IntMinusOp
        | EqOp | CommaOp | ConsOp | …
# type const = BoolConst of bool | IntConst of int |
…
# type exp = VarExp of string | ConstExp of const
   | BinOpAppExp of bin_op * exp * exp  | …
```

- How to represent (6, 3) as an exp?
- BinOpAppExp (CommaOp, ConstExp (IntConst 6),
  ConstExp (IntConst 3))

Recursive Data Types

```
# type bin_op = IntPlusOp |  IntMinusOp
        | EqOp | CommaOp | ConsOp | …
# type const = BoolConst of bool | IntConst of int |
…
# type exp = VarExp of string | ConstExp of const
   | BinOpAppExp of bin_op * exp * exp  | …
```

- How to represent [(6, 3)] as an exp?
- BinOpAppExp (ConsOp, BinOpAppExp (CommaOp, ConstExp (IntConst 6), ConstExp (IntConst 3)), ConstExp NilConst)));;

Your turn now

Try Problem 1 on MP5

Recursive Data Types

type int_Bin_Tree =
Leaf of int | Node of (int_Bin_Tree *
int_Bin_Tree);;

type int_Bin_Tree = Leaf of int | Node of (int_Bin_Tree * int_Bin_Tree)

Recursive Data Type Values

let bin_tree =
Node(Node(Leaf 3, Leaf 6),Leaf (-7));;

val bin_tree : int_Bin_Tree = Node (Node (Leaf 3, Leaf 6), Leaf (-7))

Recursive Data Type Values

bin_tree = Node

Node Leaf (-7)

Leaf 3 Leaf 6

Recursive Functions

let rec first_leaf_value tree =
match tree with (Leaf n) -> n
| Node (left_tree, right_tree) ->
first_leaf_value left_tree;;

val first_leaf_value : int_Bin_Tree -> int = <fun>

let left = first_leaf_value bin_tree;;

val left : int = 3

Problem

type int_Bin_Tree =Leaf of int
| Node of (int_Bin_Tree * int_Bin_Tree);;

- Write sum_tree : int_Bin_Tree -> int
- Adds all ints in tree

let rec sum_tree t =

Problem

type int_Bin_Tree =Leaf of int
| Node of (int_Bin_Tree * int_Bin_Tree);;

- Write sum_tree : int_Bin_Tree -> int
- Adds all ints in tree

```
let rec sum_tree t =
    match t with Leaf n -> n
    | Node(t1,t2) -> sum_tree t1 + sum_tree t2
```


Mapping over Recursive Types

```
# let rec ibtreeMap f tree =
   match tree with (Leaf n) -> Leaf (f n)
   | Node (left_tree, right_tree) ->
    Node (ibtreeMap f left_tree,
          ibtreeMap f right_tree);;
val ibtreeMap : (int -> int) -> int_Bin_Tree ->
  int_Bin_Tree = <fun>
```


Mapping over Recursive Types

```
# ibtreeMap ((+) 2) bin_tree;;

- : int_Bin_Tree = Node (Node (Leaf 5, Leaf
  8), Leaf (-5))
```


Folding over Recursive Types

```
# let rec ibtreeFoldRight leafFun nodeFun tree =
   match tree with Leaf n -> leafFun n
   | Node (left_tree, right_tree) ->
    nodeFun
    (ibtreeFoldRight leafFun nodeFun left_tree)
    (ibtreeFoldRight leafFun nodeFun right_tree);;
val ibtreeFoldRight : (int -> 'a) -> ('a -> 'a -> 'a) ->
  int_Bin_Tree -> 'a = <fun>
```


Folding over Recursive Types

```
# let tree_sum =
   ibtreeFoldRight (fun x -> x) (+);;
val tree_sum : int_Bin_Tree -> int = <fun>
# tree_sum bin_tree;;
- : int = 2
```